DIVISION 5

SECTION 3105F – MOORING AND BERTHING ANALYSIS AND DESIGN

3105F.1 General

3105F.1.1 Purpose. This Section establishes minimum standards for safe mooring and berthing of vessels at MOTs.

3105F.1.2 Applicability. This Section applies to onshore MOTs; Figure 31F-5-1 shows typical pier and wharf configurations.

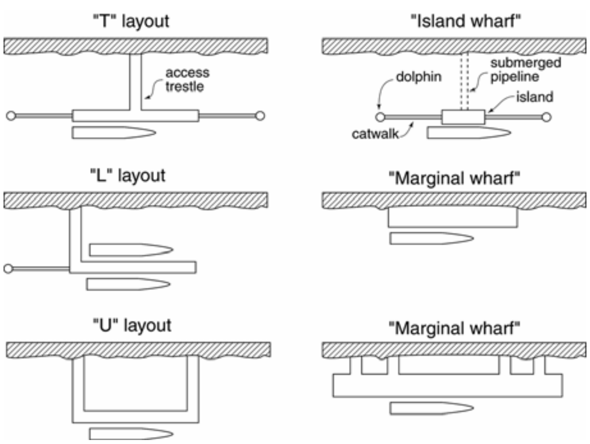

Figure31F-5-1: Typical Pier and Wharf Configurations

3105F.1.3 Mooring/Berthing Risk Classification. Each MOT shall be assigned a mooring/berthing risk classification of high, medium or low, as determined from Table 31F-5-1, based on the following site-specific parameters:

1. Wind
2. Current
3. Hydrodynamic effects of passing vessels
4. Change in vessel draft

Exceedance of any of the defined condition thresholds in Table 31F-5-1 places the MOT in the appropriate mooring/berthing risk classification.

The maximum wind, V_w, (corrected for duration, height and over water) and maximum current, V_c, shall be obtained (see subsection 3103F.5).

In order to determine if there are significant potential passing vessel effects on moored vessels at an MOT, see subsection 3105F.3.2.

The range of vessel draft shall be based on the local tidal variation and the operational limits of the vessels berthing at the MOT.

Multiple berth MOTs shall use the same conditions for each berth unless it can be demonstrated that there are significant differences.

MOTs with high mooring/berthing risk classifications (Table 31F-5-1) shall have the following equipment in operation: an anemometer (N/E), a current meter (N/E) (may be omitted if safety factor according to subsection 3103F.5.3.1 is applied to current) and remote reading tension load devices (N).

3105F.1.4 New MOTs. Quick release hooks are required at all new MOTs, except for spring line fittings. Quick release hooks shall be sized, within normal allowable stresses, for the safe working load of the largest size mooring line and configuration. To avoid accidental release, the freeing mechanism shall be activated by a two-step process. Quick release hooks shall be insulated electrically from the mooring structure, and should be supported so as not to contact the deck.

3105F.1.5 Analysis and Design of Mooring Components. The existing condition of the MOT shall be used in the mooring analysis (see Section 3102F). Structural characteristics of the MOT, including type and configuration of mooring fittings such as bollards, bitts, hooks and capstans and

TABLE 31F-5-1

MOORING/BERTHING RISK CLASSIFICATION

Risk Classification	Wind, (V_W) (knots)	Current, (V_c) (knots)	Passing Vessel Effects	Change in Draft (ft.)
High	>50	>1.5	Yes	>8
Moderate	30 to 50	1.0 to 1.5	No	6 to 8
Low	<30	<1.0	No	<6

material properties and condition, shall be determined in accordance with subsections 3107F.4 and 3103F.10.

The analysis and design of mooring components shall be based on the loading combinations and safety factors defined in subsections 3103F.8 through 3103F.10, and in accordance with ACI 318 [5.1], AISC-LRFD [5.2] and ANSI/AF&PA NDS-1997 [5.3], as applicable.

3105F.2 Mooring Analyses. A mooring analysis shall be performed for each berthing system, to justify the safe berthing of the various deadweight capacities of vessels expected at the MOT. The forces acting on a moored vessel shall be determined in accordance with subsection 3103F.5. Mooring line and breasting load combinations shall be in accordance with subsection 3103F.8.

Two procedures, manual and numerical are available for performing mooring analyses. These procedures shall conform to either the OCIMF documents, "Mooring Equipment Guidelines" [5.4] and "Prediction of Wind and Current Loads on VLCCs" [5.5] or the Department of Defense "Mooring Design" document [5.6]. The manual procedure (subsection 3105F.2.1) may be used for barges.

A new mooring assessment shall be performed when conditions change, such as any modification in the mooring configuration, vessel size or new information indicating greater wind, current or other environmental loads.

In general, vessels shall remain in contact with the breasting or fendering system. Vessel motion (sway) of up to 2 feet off the breasting structure may be allowed under the most severe environmental loads, unless greater movement can be justified by an appropriate mooring analysis that accounts for potential dynamic effects. The allowable movement shall be consistent with mooring analysis results, indicating that forces in the mooring lines and their supports are within the allowable safety factors. Also, a check shall be made as to whether the movement is within the limitations of the cargo transfer equipment.

The most severe combination of the environmental loads has to be identified for each mooring component. At a minimum, the following conditions shall be considered:

1. Two current directions (maximum ebb and flood; See subsection 3103F.5.3)
2. Two tide levels (highest high and lowest low)
3. Two vessel loading conditions (ballast and maximum draft at the terminal)
4. Eight wind directions (45 degree increments)

3105F.2.1 Manual Procedure. For MOTs classified as Low risk (Table 31F-5-1), simplified calculations may be used to determine the mooring forces, except if any of the following conditions exist (Figures 31F-5-2 and 31F-5-3, below).

1. Mooring layout is significantly asymmetrical
2. Horizontal mooring line angles (α) on bow and stern exceed 45 degrees
3. Horizontal breast mooring line angles exceed 15 normal to the hull
4. Horizontal spring mooring line angles exceed 10 degrees from a line parallel to the hull
5. Vertical mooring line angles (Θ) exceed 25 degrees
6. Mooring lines for lateral loads not grouped at bow and stern

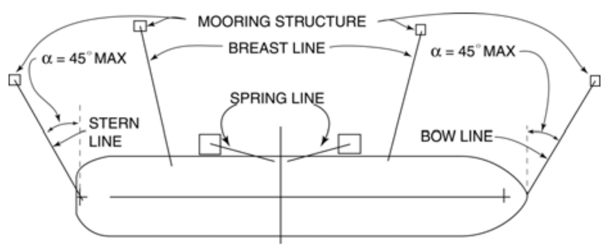

Figure 31F-5-2: Horizontal Line Angles [5.4]

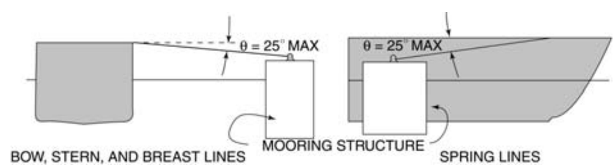

Figure 31F-5-3: Vertical Line Angles [5.4]

When the forces have been determined and the distance between the bow and stern mooring points is known, the yaw moment can be resolved into lateral loads at the bow and stern. The total environmental loads on a moored vessel are comprised of the lateral load at the vessel bow, the lateral load at the vessel stern and the longitudinal load. Line pretension loads must be added.

Four load cases shall be considered:

1. Entire load is taken by mooring lines
2. Entire load is taken by breasting structures
3. Load is taken by combination of mooring lines and breasting structures
4. Longitudinal load is taken only by spring lines

3105F.2.2 Numerical Procedure. *A numerical procedure is required to obtain mooring forces for MOTs classified as Moderate or High (See Table 31F-5-1) and for those that do not satisfy the requirements for using simplified calculations. Computer program(s) shall be based on mooring analysis procedures that consider the characteristics of the mooring system, calculate the environmental loads and provide resulting mooring line forces and vessel motions (surge and sway).*

3105F.3 WAVE, PASSING VESSEL, SEICHE AND TSUNAMI

3105F.3.1 Wind Waves. *MOTs are generally located in sheltered waters such that typical wind waves can be assumed not to affect the moored vessel if the significant wave period, T_s, is less than 4 seconds. However, if the period is equal to or greater than 4 seconds, then a simplified dynamic analysis (See subsection 3103F.5.4) is required. The wave period shall be established based on a 1-year significant wave height, H_s. For MOTs within a harbor basin, the wave period shall be based on the locally generated waves with relatively short fetch.*

3105F.3.2 Passing Vessels. *These forces generated by passing vessels are due to pressure gradients associated with the flow pattern. These pressure gradients cause the moored vessel to sway, surge, and yaw, thus imposing forces on the mooring lines.*
Passing vessel analysis shall be conducted when all of the following conditions exist (See Figure 31F-5-4):

1. *Passing vessel size is greater than 25,000 dwt.*
2. *Distance L is 500 feet or less*
3. *Vessel speed V is greater than V_{crit}*

where:

$$V_{crit} = 1.5 + \frac{L - 2B}{500 - 2B} 4.5 \text{ (knots)} \qquad (5\text{-}1)$$

Exception: If $L \leq 2B$, passing vessel loads shall be considered.

L and B are shown in Figure 31F-5-4, in units of feet. V is defined as the speed of vessel over land minus the current velocity, when traveling with the current, or the speed of vessel over land plus the current velocity, when traveling against the current.

When such conditions (1, 2 and 3 above) exist, the surge and sway forces and the yaw moment acting on the moored vessel shall, as a minimum, be established in accordance with subsection 3103F.5.5. If the demands from such evaluation are greater than 75% of the mooring system capacity (breaking strength of mooring lines), then a more sophisticated dynamic analysis is required.

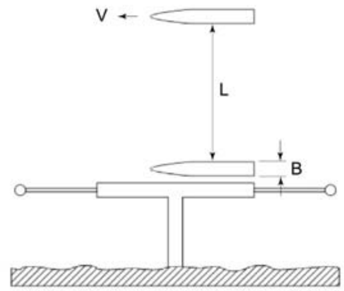

Figure 31F-5-4: Passing Vessel

For MOTs located in ports, the passing distance, L, may be established based on channel width and vessel traffic patterns. The guidelines established in the Navy's "Harbors Design Manual," Figure 27 [5.7] for interior channels may be used. The "vertical bank" in Figure 27 of [5.7] shall be replaced by the side of the moored vessel when establishing the distance, "L".

For MOTs, not located within a port, the distance, "L", must be determined from observed traffic patterns.

The following passing vessel positions shall be investigated:

1. *Passing vessel is centered on the moored ship. This position produces maximum sway force.*
2. *The mid-ship of the passing vessel is fore or aft of the centerline of the moored ship by a distance of 0.40 times the length of the moored ship. This position is assumed to produce maximum surge force and yaw moment at the same time.*

The mooring loads due to a passing vessel shall be added to the mooring loads due to wind and current.

3105F.3.3 Seiche. *A seiche analysis is required for existing MOTs located within a harbor basin and which have historically experienced seiche. A seiche analysis is required for new MOTs inside a harbor basin prone to penetration of ocean waves.*

The standing wave system or seiche is characterized by a series of "nodes" and "antinodes". Seiche typically has wave periods ranging from 20 seconds up to several hours, with wave heights in the range of 0.1 to 0.4 ft [5.7].

The following procedure may be used, as a minimum, in evaluating the effects of seiche within a harbor basin. In more complex cases where the assumptions below are not applicable, dynamic methods are required.

1. *Calculate the natural period of oscillation of the basin. The basin may be idealized as*

rectangular, closed or open at the seaward end. Use the formula provided (Eqn. 2-1, page 26.1-40) in the Navy's "Harbor Design Manual" [5.7], to calculate the wave period and length for different modes. The first three modes shall be considered in the analysis.

2. *Determine the location of the moored ship with respect to the antinode and node of the first three modes to determine the possibility of resonance.*
3. *Determine the natural period of the vessel and mooring system. The calculation shall be based on the total mass of the system and the stiffness of the mooring lines in surge. The surge motion of the moored vessel is estimated by analyzing the vessel motion as a harmonically forced linear single degree of freedom spring mass system. Methods outlined in a paper by F.A. Kilner [5.8] can be used to calculate the vessel motion.*
4. *Vessels are generally berthed parallel to the channel; therefore, only longitudinal (surge) motions shall be considered, with the associated mooring loads in the spring lines. The loads on the mooring lines (spring lines) are then determined from the computed vessel motion and the stiffness of those mooring lines.*

3105F.3.4 Tsunami. *Run-up and current velocity shall be considered in the tsunami assessment. Table 31F-3-8 provides run-up values for the San Francisco Bay area, Los Angeles/Long Beach Harbors and Port Hueneme.*

3105F.4 Berthing Analysis and Design. *In general and for new MOTs, the fender system alone shall be designed to absorb the berthing energy. For existing MOTs, the berthing analysis may include the fender and structure.*

The analysis and design of berthing components shall be based on the loading combinations and safety factors defined in subsections 3103F.8 and 3103F.9 and in accordance with ACI 318 [5.1], AISC-LRFD [5.2], and ANSI/AF&PA NDS-1997 [5.3], as applicable.

3105F.4.1 Berthing Energy Demand. *The kinetic berthing energy demand shall be determined in accordance with subsection 3103F.6.*

3105F.4.2 Berthing Energy Capacity. *For existing MOTs, the berthing energy capacity shall be calculated as the area under the force-deflection curve for the combined structure and fender system as indicated in Figure 31F-5-5. Fender piles may be included in the lateral analysis to establish the total force-deflection curve for the berthing system. Load-deflection curves for other fender types shall be obtained from manufacturer's data. The condition of fenders shall be taken into account when performing the analysis.*

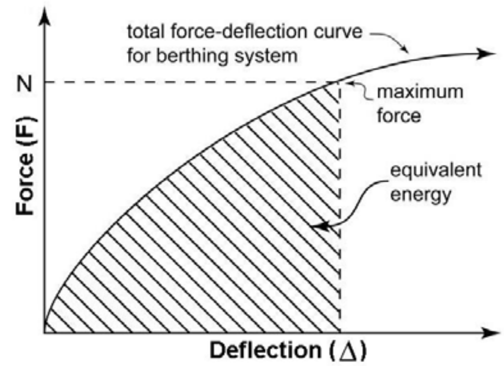

Figure 31F-5-5: Berthing Energy Capacity

When batter piles are present, the fender system typically absorbs most of the berthing energy. This can be established by comparing the force-deflection curves for the fender system and batter piles. In this case only the fender system energy absorption shall be considered.

3105F.4.3 Tanker Contact Length

3105F.4.3.1 Continuous Fender System. *A continuous fender system consists of fender piles, chocks, wales, and rubber or spring fender units.*

The contact length of a ship during berthing depends on the spacing of the fender piles and fender units, and the connection details of the chocks and wales to the fender piles.

The contact length, L_c can be approximated by the chord formed by the curvature of the bow and the berthing angle as shown in Equation 31F-5.2 below.

$$L_c = 2r \sin \alpha \qquad (5\text{-}2)$$

where:

L_c	=	*contact length*
r	=	*Bow radius*
α	=	*Berthing Angle*

In lieu of detailed analysis to determine the contact length, Table 31F-5-2 may be used. The contact length for a vessel within the range listed in the table can be obtained by interpolation.

3105F.4.3.2 Discrete Fender System. *For discrete fender systems (i.e. not continuous), one fender unit or breasting dolphin shall be able to absorb the entire berthing energy.*

TABLE 31F-5-2 CONTACT LENGTH	
Vessel Size (dwt)	**Contact Length**
330	25 ft
1,000 to 2,500	35 ft
5,000 to 26,000	40 ft
35,000 to 50,000	50 ft
65,000	60 ft
100,000 to 125,000	70 ft

3105F.4.4 Longitudinal and Vertical Berthing Forces. *The longitudinal and vertical components of the horizontal berthing force shall be calculated using appropriate coefficients of friction between the vessel and the fender. In lieu of as-built data, the values in Table 31F-5-3 may be used for typical fender/vessel materials:*

TABLE 31F-5-3 COEFFICIENT OF FRICTION	
Contact Materials	**Friction Coefficient**
Timber to Steel	0.4 to 0.6
Urethane to Steel	0.4 to 0.6
Steel to Steel	0.25
Rubber to Steel	0.6 to 0.7
UHMW* to Steel	0.1 to 0.2
*Ultra high molecular weight plastic rubbing strips	

Longitudinal and vertical forces shall be determined by:

$$F = \mu N \tag{5-3}$$

where:

F = *longitudinal or vertical component of horizontal berthing force*

μ = *coefficient of friction of contact materials*

N = *maximum horizontal berthing force (normal to fender)*

3105F.4.5 Design and Selection of New Fender Systems. *For guidelines on new fender designs, refer to the Navy's "Piers and Wharves" handbook [5.9] and the PIANC Guidelines for the Design of Fenders Systems: 2002 [5.10].*

3105F.5 Layout of New MOTs. *The number and spacing of independent mooring dolphins and breasting dolphins depends on the DWT and length overall (LOA) of vessels to be accommodated.*

Breasting dolphins shall be positioned adjacent to the parallel body of the vessel when berthed. A minimum of two breasting dolphins shall be provided. The spacing of breasting dolphins shall be adequate for all sizes of vessels that may berth at the MOT.

Mooring dolphins shall be set back from the berthing line (fender line) for a distance between 115 ft. and 165 ft., so that longer bow, stern and breast lines can be deployed.

For a preliminary layout, the guidelines in the British Standards, Part 4, Section 2 [5.11], may be used in conjunction with the guidelines below.

1. *If four breasting dolphins are provided, the spacing between exterior breasting dolphins shall be between 0.3 and 0.4 LOA of the maximum sized vessel expected to call at the MOT. The spacing between interior breasting dolphins shall be approximately 0.3 to 0.4 LOA of the minimum sized vessel expected to call at the MOT.*
2. *If only two breasting dolphins are provided, the spacing between the dolphins shall be the smaller (0.3 LOA) of the guidelines specified above.*
3. *If bow and stern lines are used for mooring, the spacing between exterior mooring dolphins shall be 1.35 times the LOA of the maximum sized vessel expected to call at the MOT.*
4. *The spacing between interior mooring dolphins shall be 0.8 times the LOA of the maximum sized vessel expected to call at the MOT.*

The final layout of the mooring and breasting dolphins shall be determined based on the results of the mooring analysis that provides optimal mooring line and breasting forces for the range of vessels to be accommodated. The breasting force under the mooring condition shall not exceed the maximum fender reaction of the fender unit when it is being compressed at the manufacturers rated deflection.

3105F.6 Symbols

α = *Berthing Angle. It also means the angle of horizontal mooring lines, see Fig 5-2*

Δ = *Deflection*

Θ = *Vertical mooring line angles*

B = *Beam of vessel*

F = *Longitudinal or vertical component of horizontal normal berthing force*

L = *Distance between passing and moored vessels*

L_c = *Contact length*

N = *Maximum horizontal berthing force*

r = *Bow radius*

μ = *Coefficient of friction of contact materials*

V = *Ground speed (knots)*

V_c = *Maximum current (knots).*

V_{crit} = *Ground speed (knots) above which passing loads must be considered*

V_w = *Maximum wind speed (knots)*

3105F.7 References

[5.1] American Concrete Institute, ACI 318-02, 2002, "Building Code Requirements for Structural Concrete (318-02) and Commentary (318R-02)," Farmington Hills, Michigan.

[5.2] American Institute of Steel Construction (AISC), 2001, "Manual of Steel Construction, Load and Resistance Factor Design (LRFD)," Third Edition, Chicago, IL.

[5.3] American Forest & Paper Association, 1999, "ASD Manual - National Design Specification for Wood Construction," ANSI/AF&PA NDS-1997, Washington, D.C.

[5.4] Oil Companies International Marine Forum (OCIMF), 1997, "Mooring Equipment Guidelines", 2nd Ed., London, England.

[5.5] Oil Companies International Marine Forum (OCIMF), 1977, "Prediction of Wind and Current Loads on VLCCs," London, England.

[5.6] Department of Defense, 1 July 1999, "Mooring Design," Handbook, MIL-HDBK-1026/4A, Alexandria, VA, USA.

[5.7] Department of the Navy, Dec. 1984, "Harbors Design Manual," NAVFAC DM-26.1, Alexandria, VA, USA.

[5.8] Kilner F.A., 1961, "Model Tests on the Motion of Moored Ships Placed on Long Waves." Proceedings of 7th Conference on Coastal Engineering, August 1960, The Hague, Netherlands, published by the Council on Wave Research - The Engineering Foundation.

[5.9] Department of the Navy, 30 October 1987, "Piers and Wharves," Military Handbook, MIL-HDBK-1025/1, Alexandria, VA, USA.

[5.10] Permanent International Association of Navigation Congresses (PIANC), 2002, "Guidelines for the Design of Fender Systems: 2002," Brussels.

[5.11] British Standards Institution, 1994, "British Standard Code of Practice for Maritime Structures - Part 4. Code of Practice for Design of Fendering and Mooring Systems", BS6349, London, England.

Authority: Sections 8755 and 8757, Public Resources Code.

Reference: Sections 8750, 8751, 8755 and 8757, Public Resources Code.